

# **Validation of Multiangle Imaging Spectro- Radiometer (MISR) Aerosol Optical Depth Retrievals Using Ground-based Solar Radiometer Observations from the Aerosol Robotic Network (AERONET)**

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## **AERONET PI's**

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# 1. Introduction

This poster describes an ongoing study to provide validation for the geophysical products supplied by the Multi-angle Imaging SpectroRadiometer (MISR) aboard the EOS AM-1 platform. EOS AM-1 was launched into polar orbit from Vandenberg AFB on December 18, 1999. After several months of platform engineering housekeeping, MISR began transmission of data constituting commencement of the MISR scientific portion of the EOS mission.

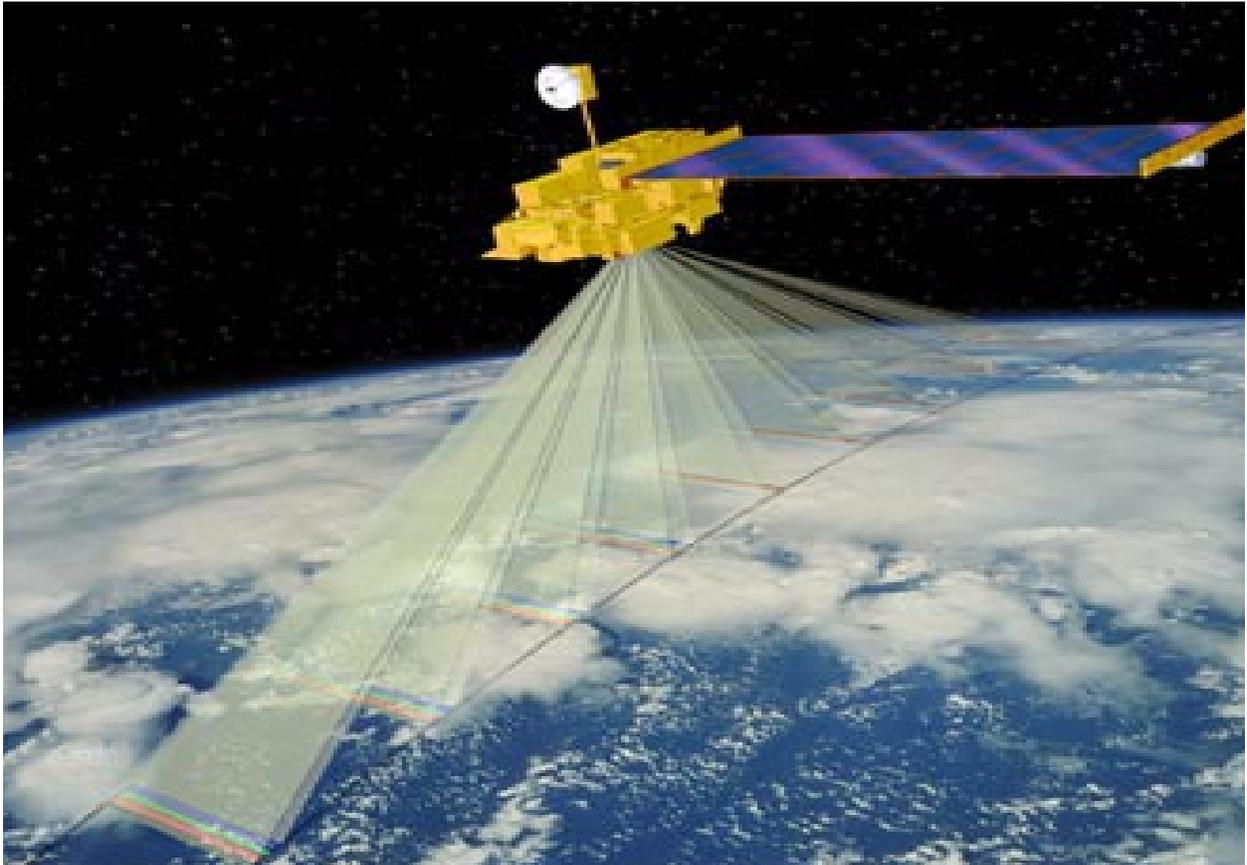
The validation work utilizes ground based measurements fielded by the MISR team (see Helmlinger, this session) as well as data taken as part of the AERONET program, further details of which may be found at:  
<http://aernet.gsfc.nasa.gov:8080>.

## 2. The MISR Instrument

MISR shares the EOS AM-1 platform with the Moderate Resolution Imaging Spectrometer (MODIS), the Clouds and the Earth's Radiant Energy System (CERES), the Advanced Spaceborne Thermal Emission and Radiation instrument (ASTER) and the Measurement Of Pollution In The Troposphere (MOPITT), designed to monitor the Earth's radiation budget and climate.

MISR is unique in that it views each point on the surface within its swath from nine view angles,  $0^\circ$ ,  $\pm 26.1^\circ$ ,  $\pm 45.6^\circ$ ,  $\pm 60^\circ$ , and  $\pm 70.5^\circ$  relative to nadir. These, together with four spectral bands (446, 558, 672, and 866 nm), give MISR a total of 36 channels.

The time sampling interval between repeat overpasses with minimum angle between ground point and orbit (e.g.,  $\sim 2^\circ$ ) is 16 days. The time sampling interval if larger angles can be tolerated (e.g.,  $2^\circ - 15^\circ$ ) is 2-7 days.



Detailed description of MISR instrument and the EOS mission can be found at <http://www-misr.jpl.nasa.gov>.

### 3. MISR Aerosol Product

The MISR aerosol product consists of a retrieval of one or more climatological models, each of which is characterized as a mixture of up to three previously chosen pure particle types. Table 1 lists the sizes and refractive indices of the MISR pure particle types.

Radiances calculated using mixtures of the pure particles are stored in a database at the Goddard Data Acquisition and Archiving Center (DAAC). Table 2 lists the characteristics of 2 of the 63 mixtures in the MISR database.

The details of the retrieval process differ over water, dense dark vegetation (DDV), and heterogeneous land, but in each case the retrieved mixture is defined by a total optical depth, and the percentage optical depths of up to three of the pure particle types. The retrieval selects those models that reproduce the observed data at sensor according to a  $\chi^2$ -based selection procedure.

The mixture composition specifies the spectral optical depth, so the retrieval is referenced to a total optical depth at 558nm (MISR green band).

**Table 1: MISR Pure Aerosol Particles**

Pure Particle type	Mode radius ( $\mu$ )	Width of size distribution ( $\sigma$ )	Refractive index (550nm)	Humidities
Tropospheric Sulfate/nitrate (accumulation mode)	0.07	1.86	1.53 - 0.0i	.7, .8, .9, .99
Stratospheric Sulfate/nitrate (accumulation mode)	0.45	1.30	1.43 -0.0i	n/a
Tropospheric Mineral Dust (prolate spheroidal)	0.47	1.0	1.53 -.0055i	n/a
Stratospheric Mineral Dust (prolate spheroidal)				
Mineral Dust (course)	1.9	2.6	1.50 -0.0i	.7, .8, .9, .99
Sea salt (accumulation mode)	0.35	2.51		
Sea salt (coarse mode)	3.30	2.03		
Black Carbon	0.012	2.00	1.75 - 0.440i	n/a
Biomass burning particles	0.13	1.80	1.43 -.0035i	n/a
Near Surface Fog	power law		1.33 - 0.00i	n/a
Thin Cirrus	fractal,		1.31 - 0.00i	n/a

Unless stated, all pure particles in the above table are considered spherical with a log-normal size distribution.

**Table 2: Example MISR Models**

<b>MISR Model Number</b>	<b>Pure Particle Constituents:</b>	<b>Fractional Optical Thickness at 550nm</b>	<b>Spectral Optical Thickness :</b>	<b>Spectral Single Scattering Albedo:</b>
<b>53: Industrial Continental</b>	<b>Sulfate/nitrate (accumulation-mode)</b>	<b>0.85</b>	<b>1.26, 1.00, 0.79, 0.54</b>	<b>0.838 0.841 0.839, 0.824</b>
	<b>Mineral dust (accumulation mode)</b>	<b>0.0</b>		
	<b>Urban soot</b>	<b>0.15</b>		
<b>55: Dusty Continental</b>	<b>Sulfate/nitrate (accumulation mode)</b>	<b>0.75</b>	<b>1.18, 1.00, 0.84, 0.63</b>	<b>0.983, 0.984, 0.984, 0.983</b>
	<b>Mineral dust (accumulation mode)</b>	<b>0.25</b>		
	<b>Urban soot</b>	<b>0.0</b>		

## 4. Ground based Retrievals: AERONET

The AERONET was initiated and developed by NASA's EOS (Holben, *et al.*, 1998) and has been added to and maintained in cooperation with many non-NASA institutions. AERONET consists of a network of automated ground-based optical instruments and a data archive. The optical hardware at each site consists of a weather-hardened Sun-sky scanning spectral radiometer manufactured by CIMEL Electronique of Paris, France (hereafter referred to merely as CIMEL, or collectively as the Aeronet). These provide nearly real-time observations of direct solar irradiances, and sky radiances, as detailed in Table 3. The network presently consists of a worldwide distribution of approximately 100 instruments most of which are kept operational full time, but the instruments have occupied as many as 240 sites for various intervals of time. The AERONET project reduces the data automatically and maintains an archive of spectral aerosol optical thicknesses (AOT's), derived size distributions, and complex indices of refraction (Dubovik et al., 2000).

**Table 3: CIMEL Instrument**

Properties	Wavelengths and Angles
Wavelengths of Sun and sky radiance measurements	440, 670, 870, and 1020 nm.
Azimuth angles relative to Sun in the solar almucantar taken by CIMEL	2, 2.5, 3, 3.5, 4, 5, 6, 10, 12, 14, 16, 18, 20, 25, 30, 40, 45, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180 deg.
Scattering Angle (solar almucantar for solar zenith angle of 60°)	1.73, 2.2, 2.60, 3.1, 3.46, 4.33, 5.20, 8.66, 10.39, 12.12, 13.85, 15.57, 17.30, 21.61, 25.90, 30.199, 34.46, 38.71, 42.94, 51.32, 59.57, 67.65, 75.52, 83.12, 97.18.108.94, 117.05, 120.0 deg
Solar Irradiance measurement for Optical Depth	Every one-half air mass, sunrise to sunset
Solar Almucantar Scan	Eight times/day
Solar Principal Plane Scan	Eight times/day

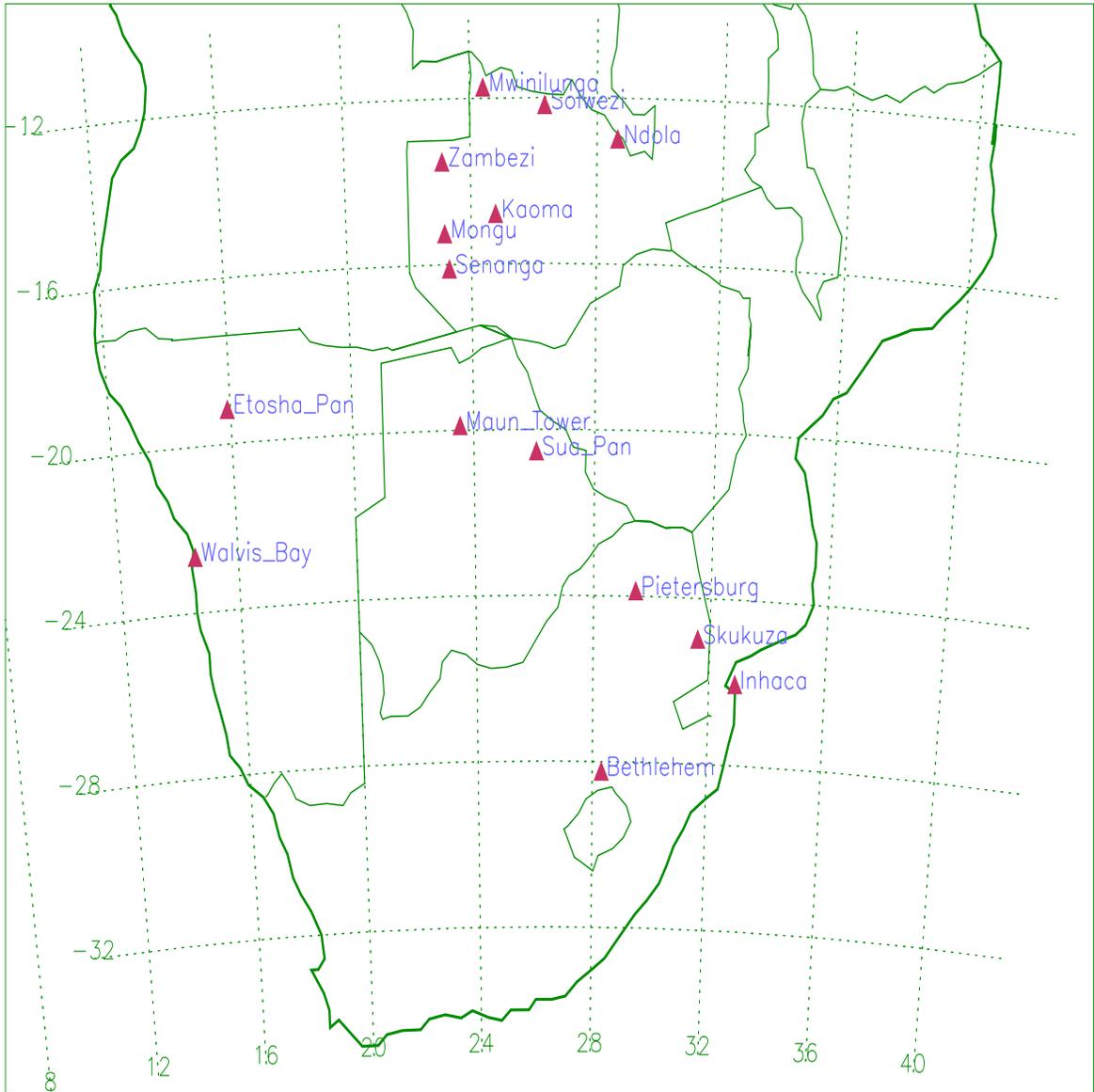
## 5. Co-location of Data Sets

MISR validation strategy relies on comparing the MISR aerosol retrievals with aerosol retrievals derived from ground observations. Automated software polls the AERONET website for data taken at times and sites of Terra overpasses.

A map of the Aeronet measurement sites used in the present work are shown in Figure 1. Two groups of sites are shown, those associated with the Southern African Fire And Radiation (SAFARI 2000) experiment, and also a set of local sites used for validation in the Southwestern US.

The MISR validation strategy relies on a study of the average correlation between MISR and ground based retrievals seen across the globe, as well as on the detailed investigation of individual sites.

SAFARI 2000 AERONET Sites, Southern Africa



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Figure 1.A

AERONET Sites, Southwest US

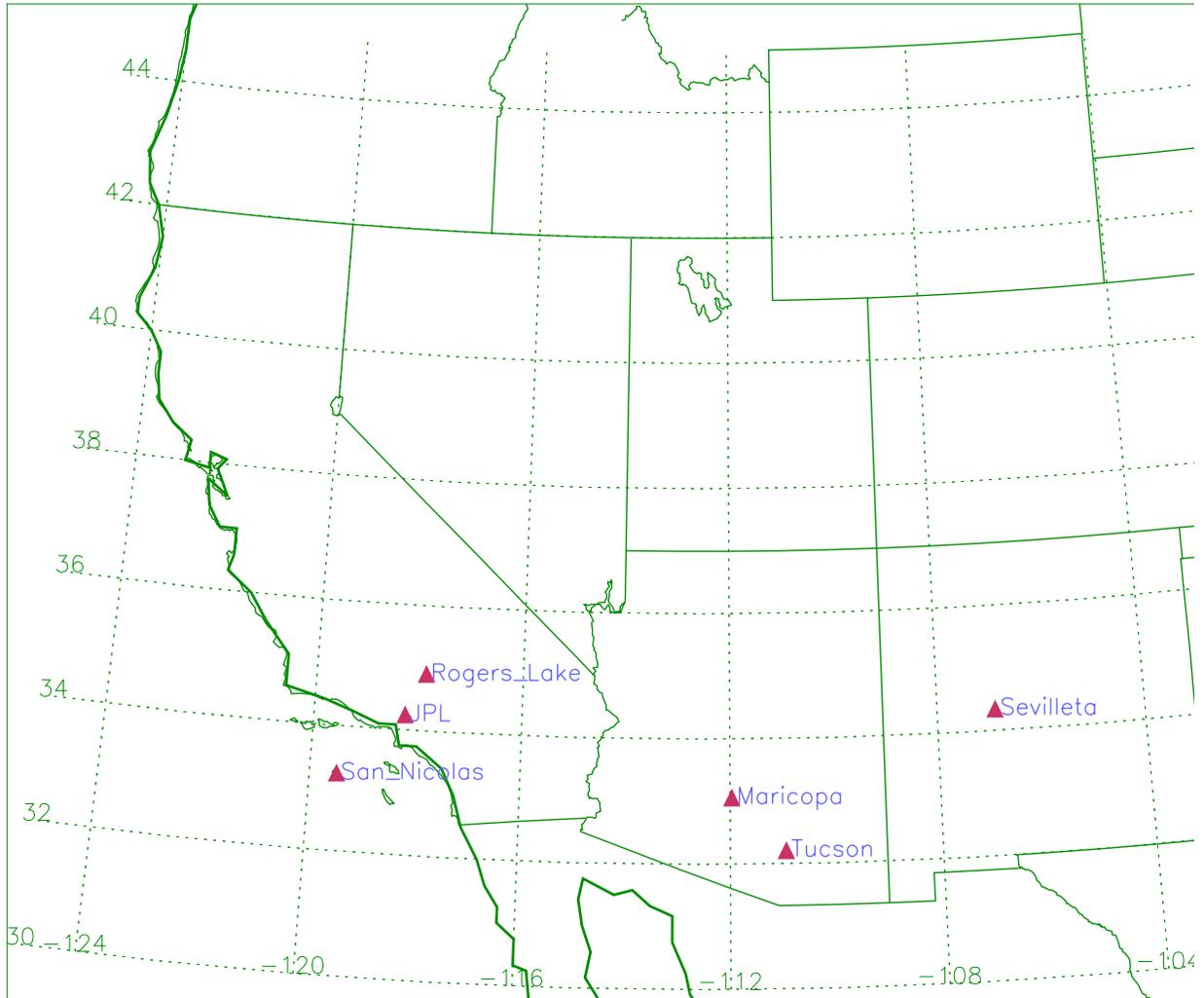


Figure 1.B

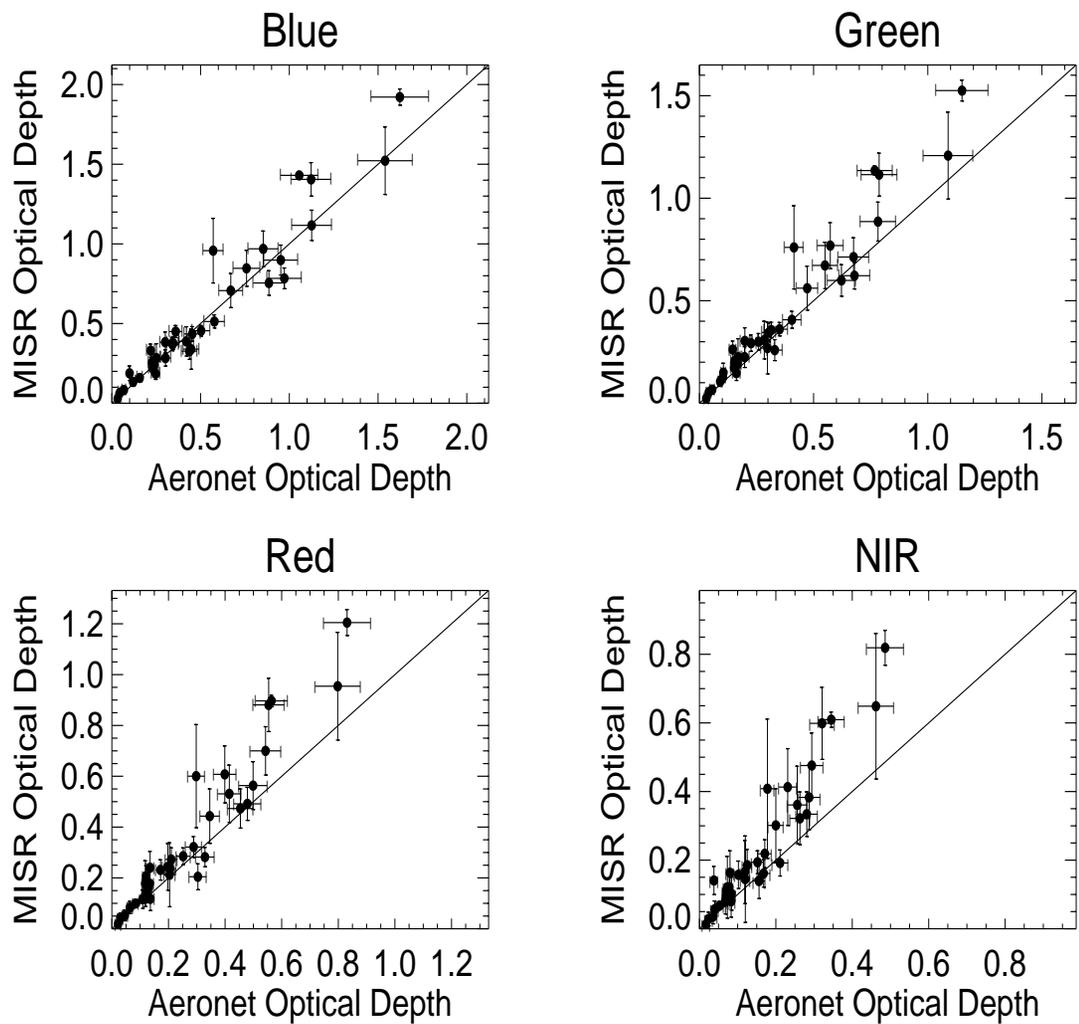
## 6. “Global” Comparison of Aerosol Optical Thicknesses (AOT)

Figure 2A is a plot of the optical thicknesses derived from the SAFARI AERONET sites versus MISR retrievals, for the satellite overpasses of each site when data were collected. The AERONET data have been interpolated to the wavelengths of the MISR bands, and the comparison is shown at all four MISR bands. Figure 2B shows the same thing for AERONET sites in Southern California.

The error bars applied to the MISR retrievals reflect the standard deviation of all MISR retrievals with a low chi square value from all the 17.6km pixels adjoining that containing the site. The error bars on the AERONET retrievals are the maximum of 10% of the AOT or 0.01.

Figure 2 shows that there is fairly good overall agreement between MISR and Aeronet retrievals. However, MISR-predicted optical depths are often brighter than the AERONET retrievals. In case of the Safari data, Figure 2A, this is so in regions of high optical depths and the correlation gets poorer at longer wavelengths. In case of the Southwest US data, Figure 2B, the correlation is poorer at shorter wavelengths.

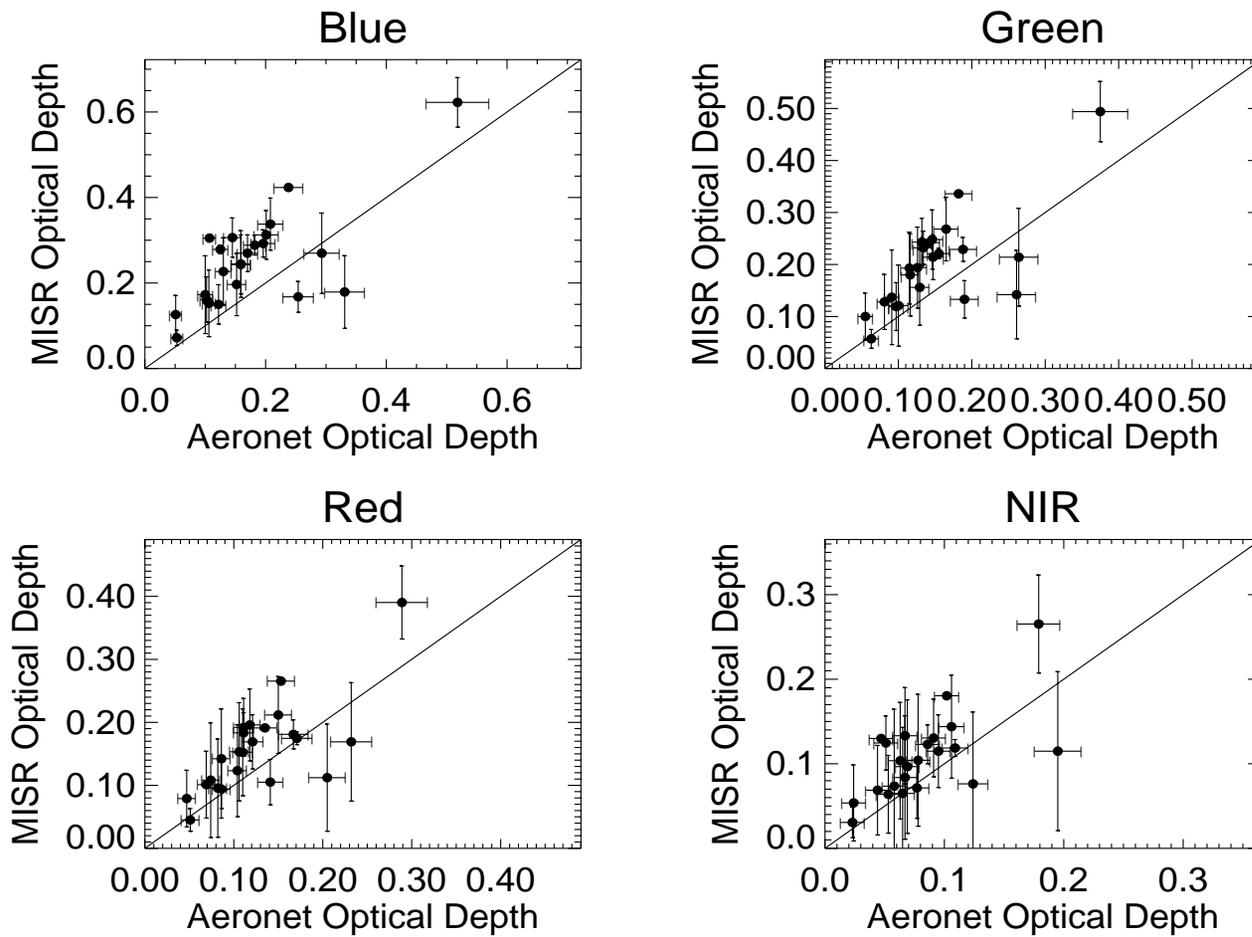
MISR Aeronet Comparison - Safari 2000



Average over models and surrounding regions

Figure 2A.

### MISR Aeronet Comparison - South West US



Average over models and surrounding regions

Figure 2B.

## 6.1 Analysis

Detailed investigation reveals that the deviations from correlation are related to a variety of factors. The least systematic of these are, for example, the presence of high cirrus clouds which are in evidence in the MISR images taken at 70deg, but not detected on the ground.

The differences in the correlations between Figures 2A and 2B certainly result partly from systematic differences in the aerosol climatologies of central Africa and the southwestern US, which can probably not be described by the same set of aerosol models. The MISR retrieval implemented at launch contains only a subset of the planned 14 land and 49 water models calculated. Over land, this initial subset consists of various mixtures of sulfates, coarse mode mineral dust, and carbonaceous soot.

The global data also helps to find other systematic factors in the AOT retrieval. In the cases presented it is desirable to check whether the MISR model selections could be influenced by details of the Heterogeneous Land aerosol retrieval algorithm causing it to flag brightly reflecting aerosols over bright sites.

Use of other ground measurements, such as the downwelling radiance from the CIMEL, aids in analysing the MISR retrieval of the aerosol type and, if necessary, in improving/modifying the MISR climatological database.

## **7. Specific Site Comparisons: An Example.**

The site used for this analysis is Sua Pan (-20.5N, 26.4E) on September 3, 2000. Figure 3 shows the spectral AOT derived from CIMEL measurements at the site at 8:29 GMT, along with the retrieval obtained using the MISR data from the nearest coincident Terra overpass, on the same date at 8:51 GMT.

The MISR model estimates a relatively higher optical depth at redder wavelengths than observed from the ground. As the MISR retrieval is based upon a reflection model, this would lend credence to the theory that in this instance the MISR mixture model has particles which are too large compared with what is actually in the atmosphere (small particles do not reflect red light as efficiently).

A check on this is found using the downwelling radiance measured by the CIMEL at the same time.

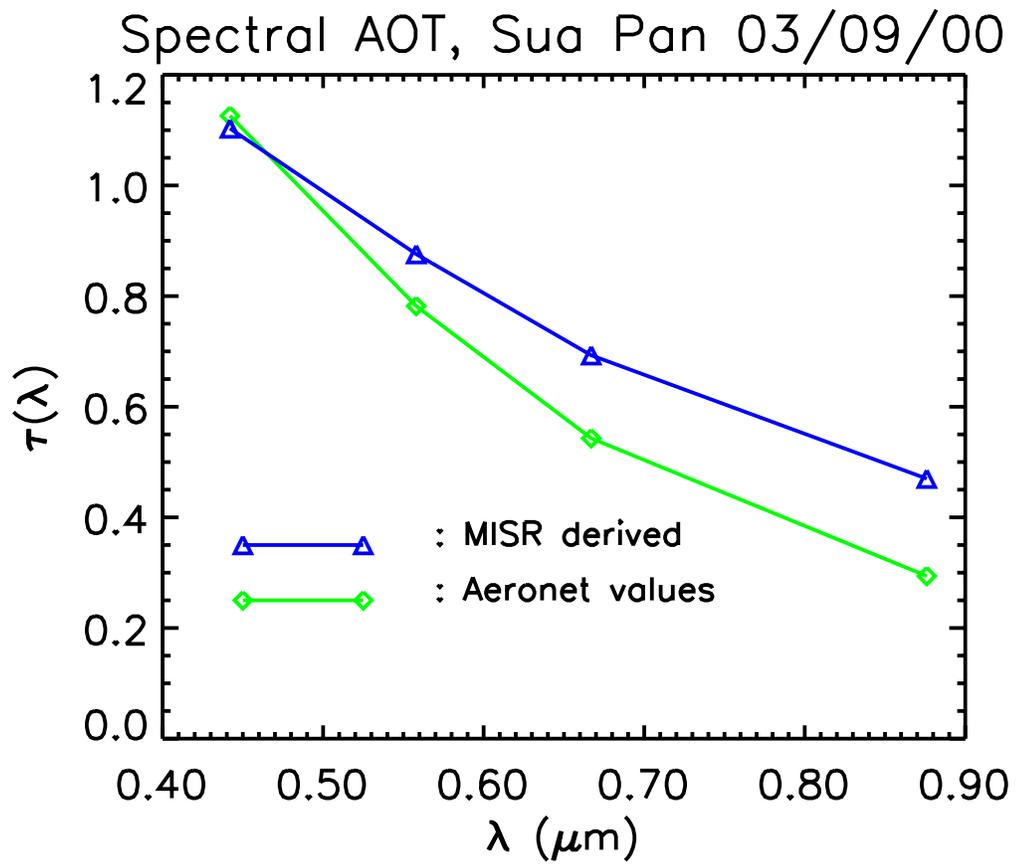


Figure 3.

## 7.1 Downwelling Radiance Comparison

The downwelling radiance is shown in Figure 4, along with that predicted using the MISR aerosol model. The MISR prediction is produced by running a radiative transfer code, using as input the MISR model together with a surface reflectance measured at the site near the time of overpass. In this case the MISR model overpredicts the scattered radiance at angles between 5 and 20° from the sun, which, in contrast to the inference from the spectral optical depth alone, is a hallmark of small particles. The sharp peak in the measured radiance at angles less than 5° from the sun is typically caused by diffraction from very large particles.

The dominant particle property in determining the shape of the downwelling radiance is the single scattering phase function; it is an intermediate data product associated with both the Aeronet and the MISR data processing. Figure 5 shows the phase functions associated with the AERONET and MISR retrievals, along with the regions in which the respective instruments sample it.

Since the CIMEL samples the forward scattered radiance directly, a check on the MISR particle database is to investigate what perturbations to the MISR pure particle types would cause better agreement in that region.

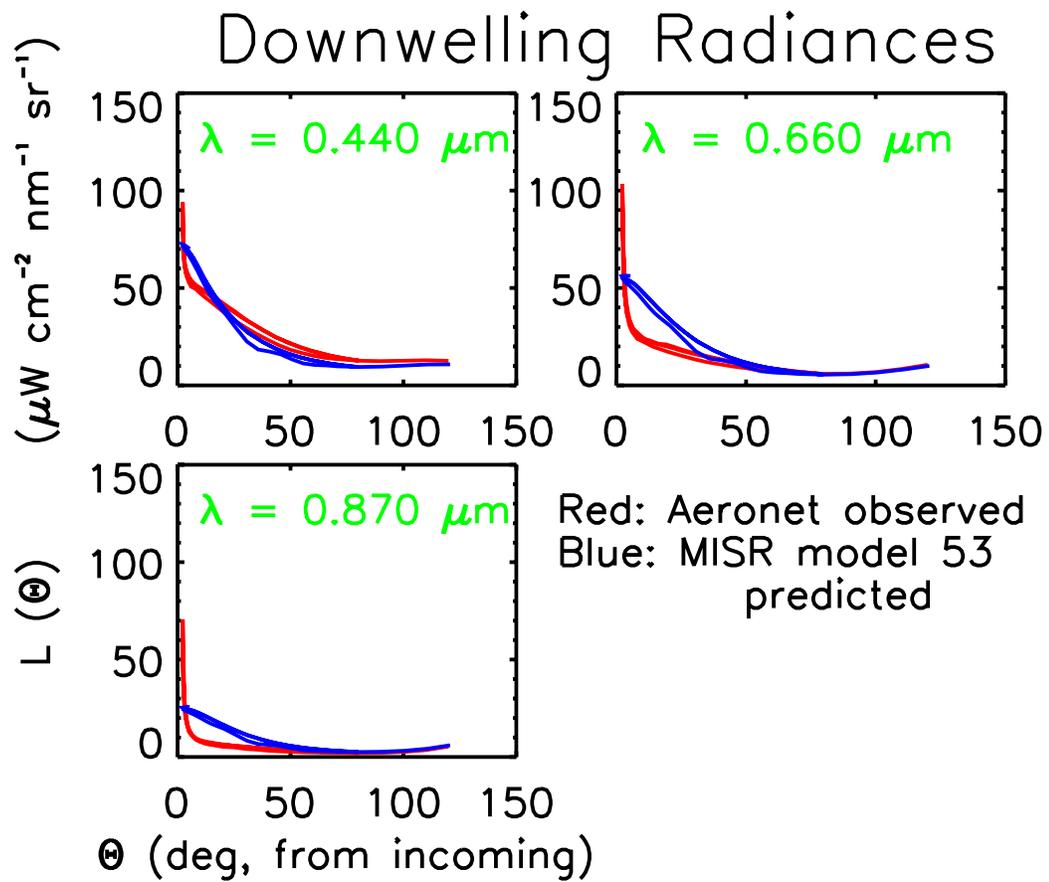


Figure 4.

# MISR model 53

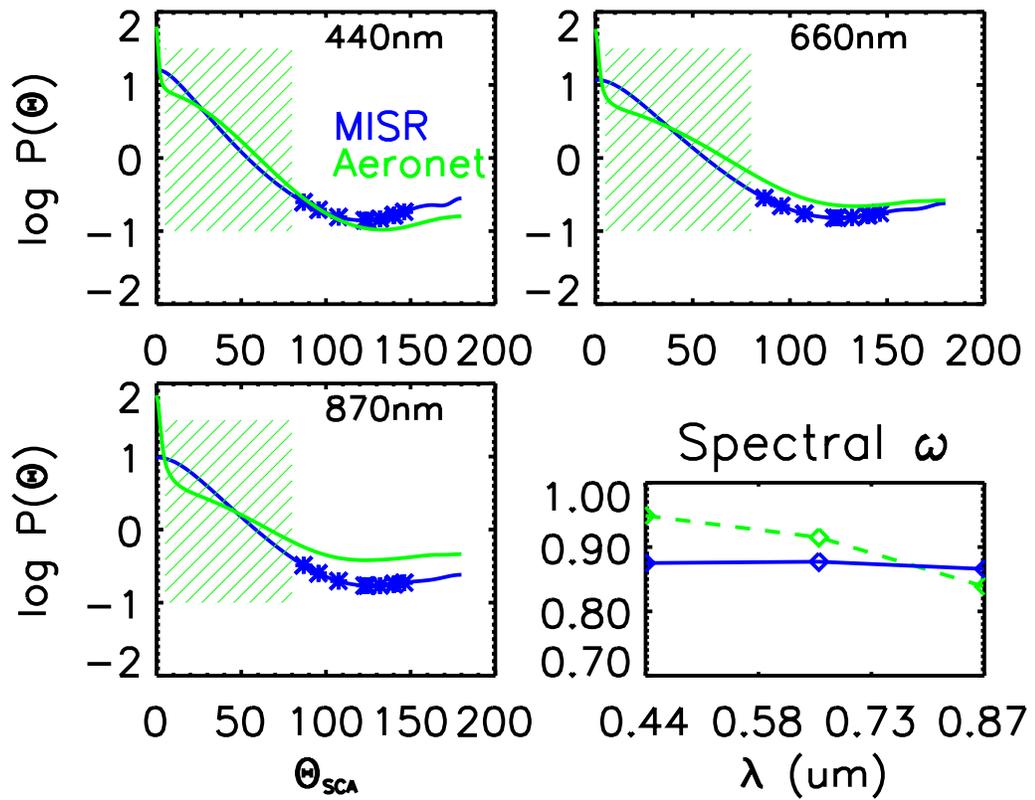


Figure 5.

## 7.2 Perturbations.

Figure 6 shows the effect of the size distribution parameter on the model predictions. Figure 6A shows the size distributions associated with the best fit MISR model (model 53, see Table 2), along with 2 different perturbations aimed at making the average particles smaller. These are shown in color, and the phase functions predicted by each of these distributions are in the same color in Figure 6B.

Also shown (dashed line, both figures) is the AERONET best fit size distribution and phase function. It can be seen that while decreasing the size of the MISR particles does indeed create a phase function that fits better, it is also important to “thin” the distribution. This has the simultaneous effect of eliminating a tail of larger particles resulting from the broad distribution. The sharp forward peak in the AERONET derived function is due almost entirely to the concentration of particles detected near  $5\mu\text{m}$ , and we do not attempt to analyse that in the present work.

# Size Distributions

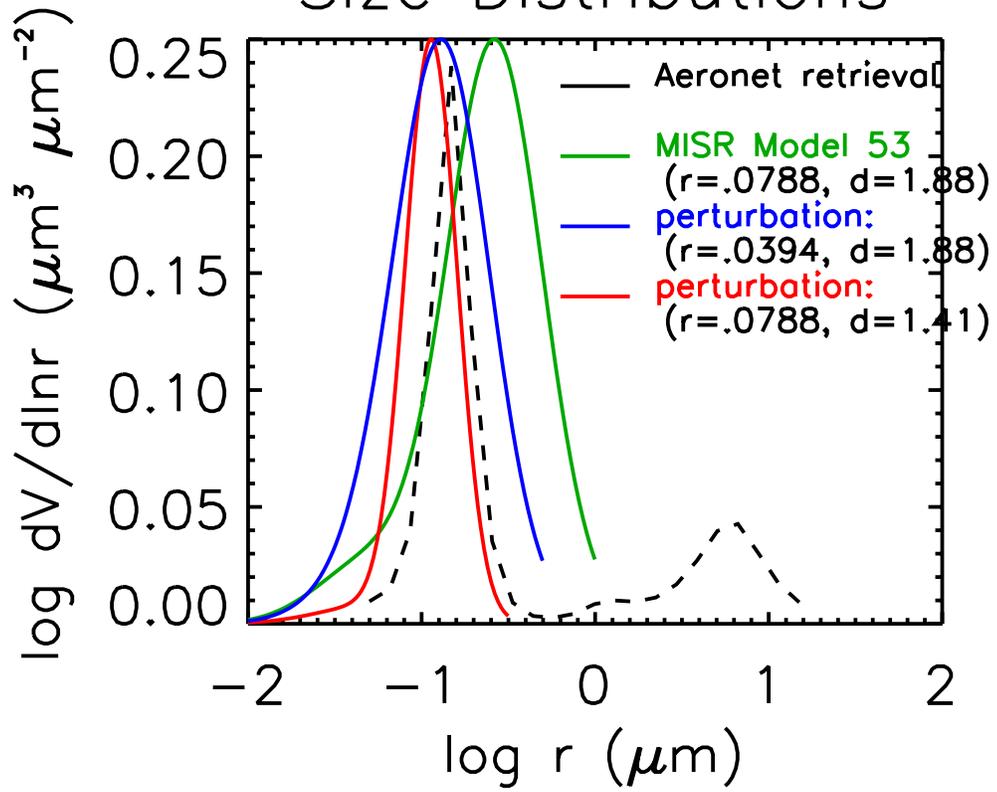


Figure 6A

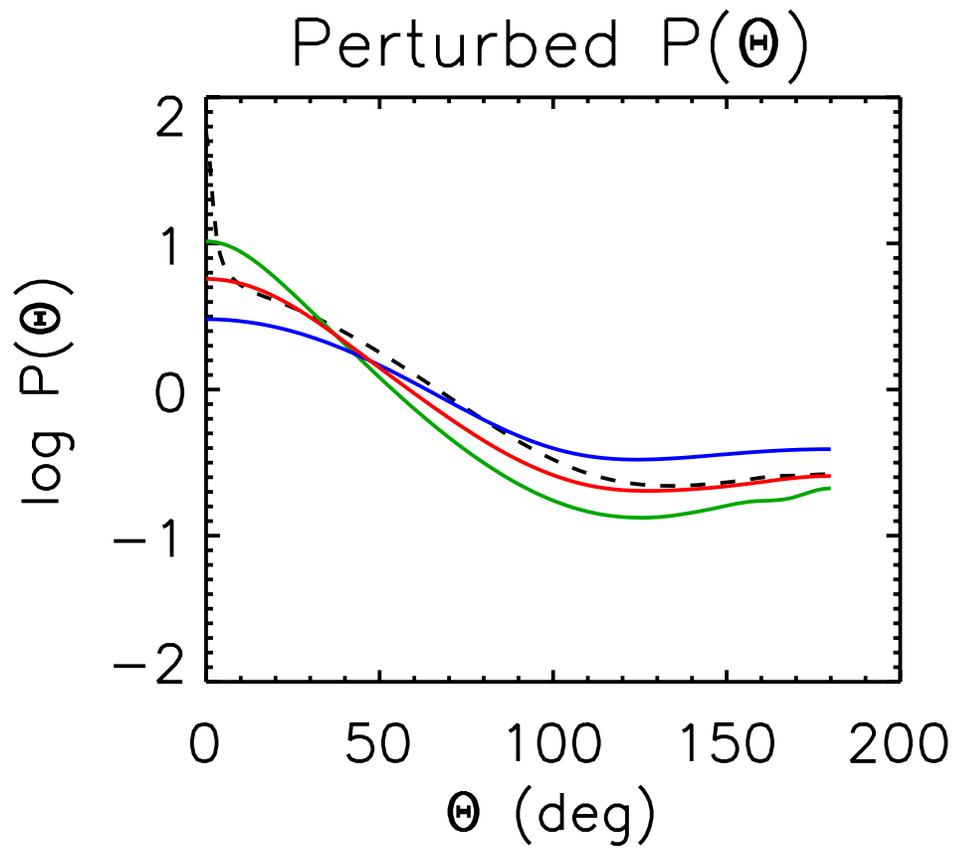


Figure 6B

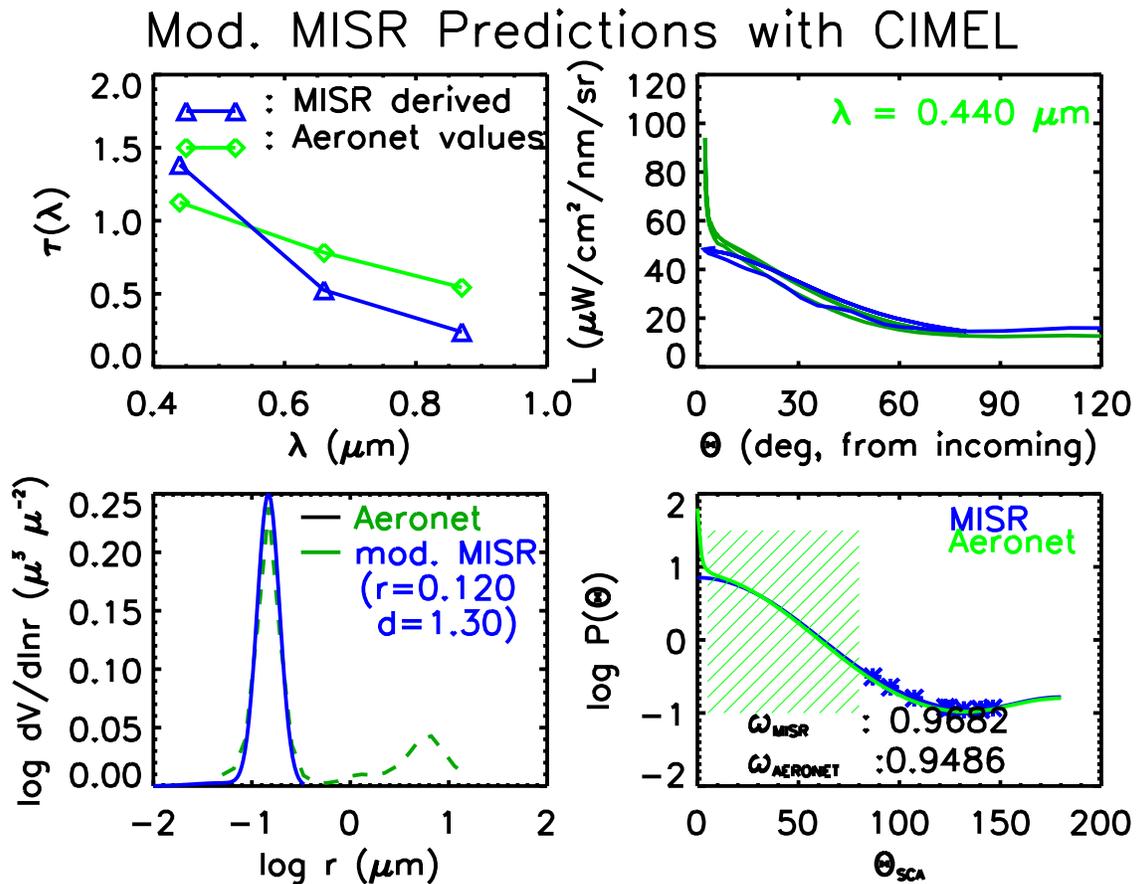


Figure 7.

Figure 7 shows the resulting improvement in the the downwelling radiance prediction which would result if the MISR database were extended to include an effectively smaller sulfate particle. The thinning of the distribution produces a forward scattered radiance peak more in line with the observed. The spectral optical depth properties are changed, and a topic of further work is to investigate the sensitivities of MISR to larger particles, which could alter these.

## 8. Summary

MISR has been in orbit and returning data for approximately 1 year. During that time, engineering check-outs and calibration have been performed, and the geophysical algorithms have been checked out for local and global mode processing. The aerosol optical thickness portion of the Level 2 Aerosol product has been released.

The objectives of the validation effort are to help find systematic idiosyncrasies or deficiencies of the geophysical product retrievals. Part of this effort utilizes comparisons of MISR retrievals co-located in time and space with those from pre-existing sites of the Aerosol Robotic NETWORK (Aeronet).

Preliminary results presented here show that the MISR aerosol retrievals reproduce the green indexed optical depth reliably. Further analysis of individual cases will help to increase the efficacy of MISR retrieval algorithms, and to design flags for situations in which caution must be used when deriving parameters.

## 9. References

Holben, B.N., *et al.*, 1998, AERONET--A federated instrument network and data archive for aerosol characterization, *Remote Sens. Environ.*, **66**, 1-16.

Dubovik, O., A. Smirnov, B.N. Holben, M.D. King, Y.J. Kaufman, T.F. Eck, and I. Slutsker, 2000, Accuracy assessments of aerosol optical properties retrieved from Aerosol Robotic Network (AERONET) Sun and sky radiance measurements, *J. Geophys. Res.*, **105 (D8)**, 9791-9806.

Diner, D., *et al.*, MISR Aerosol Product: Algorithm Theoretical Basis. JPL Document D-11400, Feb. 1994